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"A Program to Study Antiprotons in the Cosmic Rays -- Arizona Collaboration"

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A Program to Study Antiprotons in the Cosmic Rays -- Arizona Collaboration
Low Energy Anti-Protons (LEAP)

Anne Moats and Theodore Bowen

Introduction

The LEAP experiment (Low Energy AntiProton) was designed to measure the primary antiproton flux in the 200 MeV to 1 GeV kinetic energy range. A superconducting magnetic spectrometer, a time-of-flight (TOF) detector, and a Cherenkov counter are the main components of LEAP. The high-altitude flux measurement was nominally set at 125,000 feet, where contamination from antiprotons produced in the atmosphere is greatly reduced and the primary spectrum is not significantly degraded by the atmosphere above.[1]

The Cherenkov counter was the responsibility of the University of Arizona group. Using FC72, a liquid fluorocarbon with an index of refraction of 1.25, as the Cherenkov medium, the counter would be able to distinguish antiprotons from 600 MeV to 1 GeV. In addition, a search for antihelium and a measurement of the low-energy deuteron flux would be possible.

The LEAP experiment was proposed to NASA in May 1986 for flight in August 1987 when the phase in the Solar Cycle, as well as the upper wind velocities, would be optimal. We were informed in October 1986 that this project would be funded, but as no official authorization was granted to initiate a project with a very tight schedule, the design work at Arizona began in the fall of 1986 with National Science Foundation support, Grant No. PHY-85-11177. During this phase of the project tests were carried out on magnetic shielding for photomultiplier tubes (PMT's) in a Helmholtz pair magnet in the Arizona group's laboratory. This work led to the design decision by the LEAP collaboration to use special Hamamatsu PMT's, which require no magnetic shielding; the payload was not only lightened, but the need to map the magnetic field of the balloon-borne superconducting magnet was eliminated.

During this period a ^{137}Cs light source was developed to provide a realistic means of comparing and evaluating various PMT's. This light source later proved invaluable in the tune-up of the 16 PMT's in the Cherenkov counter, and in the evaluation of the counter's performance. At the same time, the mechanical design of the Cherenkov counter was carried forward. A novel design was required to deal with the highly volatile, very expensive FC72 liquid, yet maintain compact dimensions, light weight, and mechanical strength. The plans immediately went to the University machine shop when at last, four months later, NASA support was authorized to begin February 15, 1987.

From February 15, 1987 to June 1987, the final design and construction of the counter was completed. An additional scintillator detector was also designed and constructed to detect the passage of particles through the bottom of the Cherenkov counter. Finally, the LEAP package was launched on August 22, 1987, and enjoyed a 27-hour flight, with 23 hours of data at high altitude.

Cherenkov Counter Design and Construction

One of the major achievements since February 15 was the completion of the final design and construction of the counter. In the final design, the liquid FC72 was held in a 17.75" x 17.75" x 5" Plexiglas box. This box was viewed by 16 Hamamatsu R2490-01 photomultiplier tubes, held in place by an aluminum box that surrounded the Plexiglas box. Under the counter, we placed a scintillation detector, also designed and constructed during this time. The entire counter then weighed 142 pounds, an important consideration in balloon-borne experiments.

The box was constructed of UVA (ultraviolet absorbing) Plexiglas with 3/16" thick top and bottom walls and 3/8" thick side walls. As shown in Figure 1, the box had two projections, a filling nipple and a venting nipple, allowing the filling and venting of FC72 into and out of the Plexiglas box. The inside surface was coated with a wavelength shifter mixture (p-Terphenyl, Bis-MSB, and PPO) referred to as "blue waveshifter" by W. Viehmann and R. L. Frost.[2] The wavelength shifter allowed us to detect the ultraviolet part of the Cherenkov spectrum. Since the coating was on the inner surface of the box, UVA (ultraviolet absorbing) Plexiglas was employed, as it produces less scintillation light.

Immediately surrounding this clear box was an aluminum box, shown in Figure 2, providing light-tightness necessary for the low light production in the counter and providing a system for holding the photomultiplier tubes in place. The bottom piece, excluding the tube holders (projections on the four sides), was cut from a single piece of 1/16" aluminum and folded into position and the seams were welded. The top is a separate removable piece, complete with projections which allow clearance for the Plexiglas fill and vent nipples and allow the necessary tubing to be attached to the Plexiglas nipples and fed through to the outside. The top piece was attached to the rest of the box with black optical tape. The inside surface of the aluminum box was painted with $BaSO_4$ paint.[3] This highly reflective paint allowed us to collect a large fraction of the Cherenkov light generated by each particle.[4] Sixteen 2"-diameter Hamamatsu tubes viewed this box, each bordered by a 1/4" non-reflective area (the layers of 1/4" thick foam used to stabilize the tubes in position). The estimated efficiency factor of the white box was roughly 38%.

The Hamamatsu R2490-01 photomultiplier tubes are able to operate without magnetic shielding in the 500-1000 gauss magnetic field present at the counter's positon due to the magnetic spectrometer above, provided that the photomultiplier tube's axis is parallel to the magnetic field line direction within 5°. Thus, to accomodate the Hamamatsu tubes, each projection of the aluminum box had to be attached at a specific angle. If heavy iron shields had been necessary, they would have distorted the magnetic field, requiring intensive mapping of the field.

A numerical solution, developed using a computer model of the LEAP magnet, determined the direction of the magnetic field lines. To test the resulting tube angles, a coil of approximately the same dimensions as the superconducting magnet on LEAP generated a low-magnitude test field. A cardboard mock-up of the aluminum box with its tube projections was constructed and placed in the same relative position to the magnet as on the flight. A Bell 640 incremental magnetometer measured the direction of the field at each tube holder and determined that each photomultiplier tube axis was parallel to the magnetic field lines.

The filling system used to fill the counter with FC72 while in place in the LEAP system is shown in Figure 3. Clear Tygon tubing, 1/4" inner diameter, attached to both the inlet and vent nipples of the Plexiglas box, was fed through the fitting on the aluminum box cover, then attached to copper tubing formed into four spiral turns. The Tygon tubing was covered with two layers of black shrink-wrap tubing. This shrink-wrap and the copper tubing spirals prevented light from entering the counter through the inlet and outlet tubing, completing the light-tightness of the system. Both the fill and vent lines were attached to an outside 1-liter reservoir directly vented to atmospheric pressure. This reservoir allows the FC72 to thermally expand and contract during the flight without pressurizing and damaging the Plexiglas box. To discourage evaporation of the highly volatile FC72 fluid, the reservoir lid was fitted to a long 1/8" inner diameter tube that circled the inner wall of the gondola for two full turns. This provided a long diffusion length of approximately 36 feet and would prevent leakage if the gondola did not land upright after the flight.

The general electronic layout of the counter is shown in Figure 4. Two Spellman 3 kV high-voltage supplies provided high voltage to the 16 photomultiplier tubes in the Cherenkov counter and to the additional photomultiplier tube in the S2 scintillation detector. Tubes 1-8 were powered by one supply, tubes 9-16 and the S2 scintillator with the other.

Thus, the failure of one power supply unit would not disable the counter completely. The voltage from each supply, set at 2,700 volts, was fed through splitter boxes, also built at Arizona during this time period. Each splitter box was essentially a group of voltage-dropping resistors constructed with 5 megohm potentiometers. A voltage measurement point for each tube was also included, which was monitored with an electrostatic voltmeter during voltage adjustment and subsequent stability checks.

When the decision was made to employ Hamamatsu PMT's without magnetic shielding rather than 5"-diameter "teacup" PMT's, it was realized that the Hamamatsu PMT would require a gain of 10 external amplifier because of its lower gain. The Arizona group designed and built in-house 2 NIM modules, each containing 8 pulse amplifiers based upon 400 MHz Avantek GPD-110 integrated circuit amplifiers (Figure 5). As an alternative ultilizing more battery power, LeCroy Model 612A amplifiers were also obtained. The Arizona amplifiers proved more suitable when both were tried in the final payload configuration because the LeCroy amplifier response extended down to dc, which amplified 20 kHz noise due to power supply inverters in the payload. The Arizona modules, on the other hand, were ac coupled and attenuated this noise, resulting in much more stable pedestal levels in the ADC's.

The voltage applied to each photomultiplier tube was balanced using a previously constructed light source so that the pulse heights of each tube were equal when viewing the light source. The light source used the internal conversion electrons (662 KeV)[4] from a point ^{137}Cs source embedded in a 1/10"-radius sphere of plastic scintillator to provide a fixed pulse of light. The resulting pulses from the Hamamatsu PMT's were measured with a LeCroy model 3001 multi-channel anlyzer in the charge-integrating mode.

Design and Construction of Scintillation Counter S2

The scintillator placed directly under the Cherenkov counter was designed to detect the exit of particles from the bottom of the Cherenkov counter. Thus, particles that either missed the Cherenkov radiation or ranged out in the FC72 medium could be identified. The scintillator, designated as S2 in LEAP, was a 1/4"-thick piece of plastic scintillator (17.5" x 17.5") enclosed in reflecting aluminum foil and black optical tape. Looking upwards at the scintillator was a Hamamatsu R2490-01 photomultiplier tube in optical contact via a wafer of clear silicone rubber (silastic) and coupling grease, held in place by a cylindrical aluminum housing, a foam rubber "spring" below the PMT base, and additional taping (Figure 6). The tube was centered on the scintillator slab ,since this was coincidentally the position where the magnetic field lines were perpendicular to the plane of S2 and, thus, parallel to the tube axis.

Integration into LEAP

During May and June, the Arizona Cherenkov detector was integrated into the entire LEAP payload in Las Cruces, New Mexico. The Cherenkov counter, S2, the supporting Hexcel layers (aluminum honeycomb material), and other supports were placed at the bottom of the stack.

From July 10 until launch in August, payload integration and testing continued at the launch site in Prince Albert, Canada. With the trigger operational and the on-line software installed, the $\beta = 1$ muon peak was used to do the final adjustment on the photomultiplier tube gains. Other miscellaneous tests, such as a test of operation under cold (4^{O}C) conditions, were performed.

In Figure 7, a sample scatter plot is shown of the square root of the total signal from the Cherenkov detector as a function of the inverse rigidity, as determined by the magnetic spectrometer on the ground in Prince Albert. Particles of a given mass are expected to fall on an ellipse on this plot, and the statistical errors should be approximately constant, independent of position on the plot. With relatively few cuts in the data, the positive and negative muon ellipse and the proton ellipse are clearly seen.

Flight

On August 22, 1987, the LEAP experiment was launched from Prince Albert. Twenty-three hours of data at float altitude of about 120,000 feet were recorded, all systems performing well. Figure 8 shows momentum ellipses like those in Figure 7, but taken from a small portion of the data monitored during flight. In Figure 8(a), the proton ellipse can be clearly seen, with perhaps some deuterons inside; and in Figure 8(b), the vertical and horizontal axes have each been re-scaled by a factor of 2 to show the alpha-particle ellipse. Preliminary plans for data anlysis include using the Micro-Vax at the University of Arizona for data reduction of the Cherenkov and S2 signals.

Personnel and Acknowledgments

Regular Arizona personnel of LEAP experiment:

Theodore Bowen, Principal Investigator
Anne Moats, Graduate Research Assistant
Charles Bridges, Undergraduate Laboratory Assistant
Martha Dimento, Undergraduate Laboratory Assistant
Steven Syracuse, Undergraduate Laboratory Assistant

In addition to those assigned to the LEAP experiment and supported by the project grant, graduate students Peter Halverson, S. C. Liew, and C. X. Chen assisted with the final assembly and checkout of the Cherenkov counter. Peter Halverson also designed and debugged the fast pulse amplifiers. Francis Merdan and John Keggler of the University Instrument Shop machined and welded all the mechanical parts; Greg Corcoran of West-fab Plastics assembled the final Plexiglas box. Many members of the Goddard and New Mexico State groups contributed suggestions and assistance which contributed greatly to the success of the efforts of the Arizona group.

References

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2. "Thin Film Waveshifter Coatings for Fluorescent Radiation Converters," W. Viehmann and R. L. Frost, Nucl. Instrum. Methods 167, 405 (1979).

3. "Formulation Procedure and Spectral Data for a Highly Reflecting Coating from 200 nm to 2300 nm," C. M. Shai and J. B. Schutt, Note X-762-71-266, NASA/Goddard Space Flight Center (July 1971).

4. Particle Properties Data Booklet, Berkeley Particle Data Group (April 1986), p. 83.

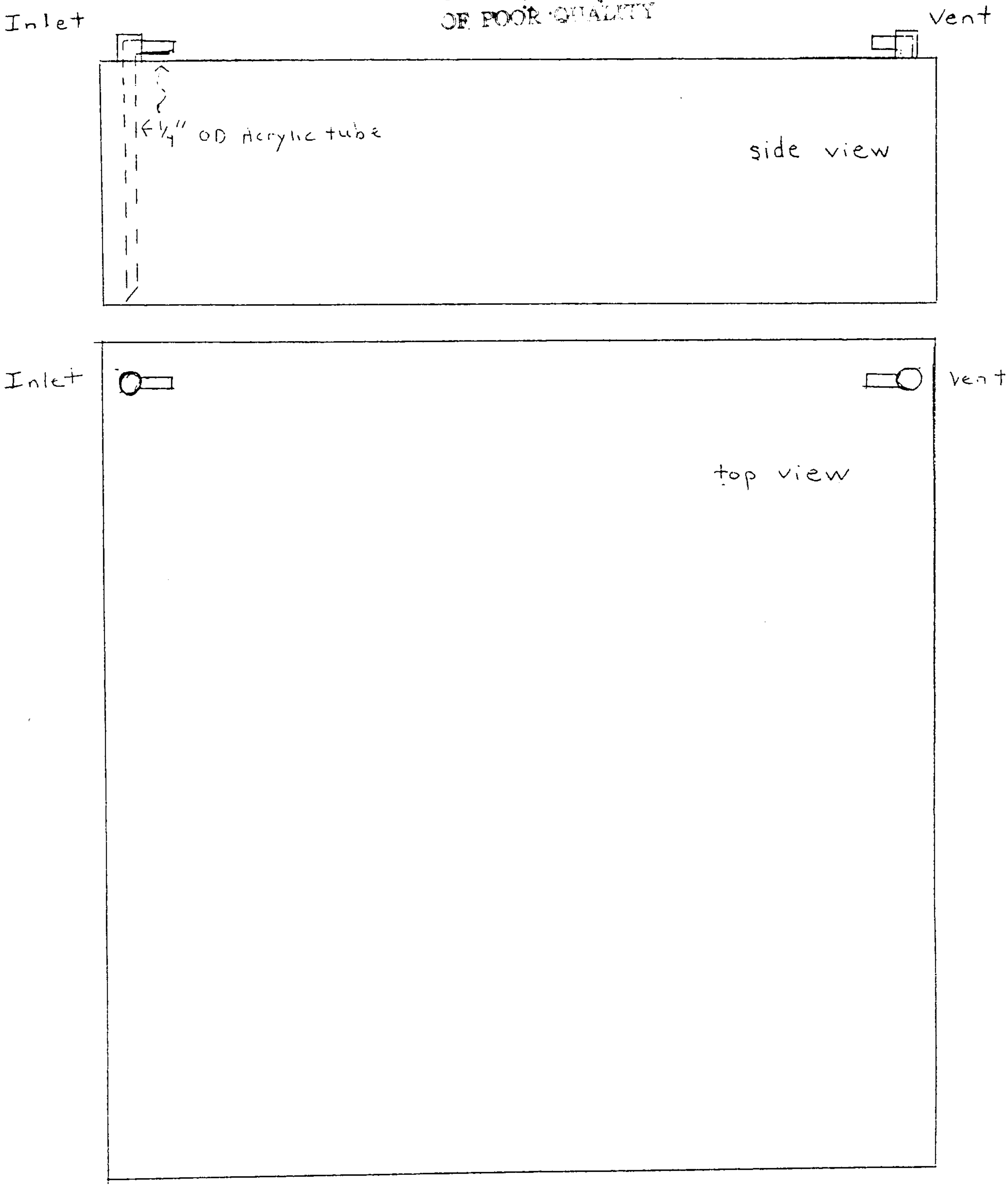

Fig. 1. Clear UVA Plexiglas box that holds the FC72. The walls are 1/4" thick and the whole box measures 17.75" x 17.75" x 5".

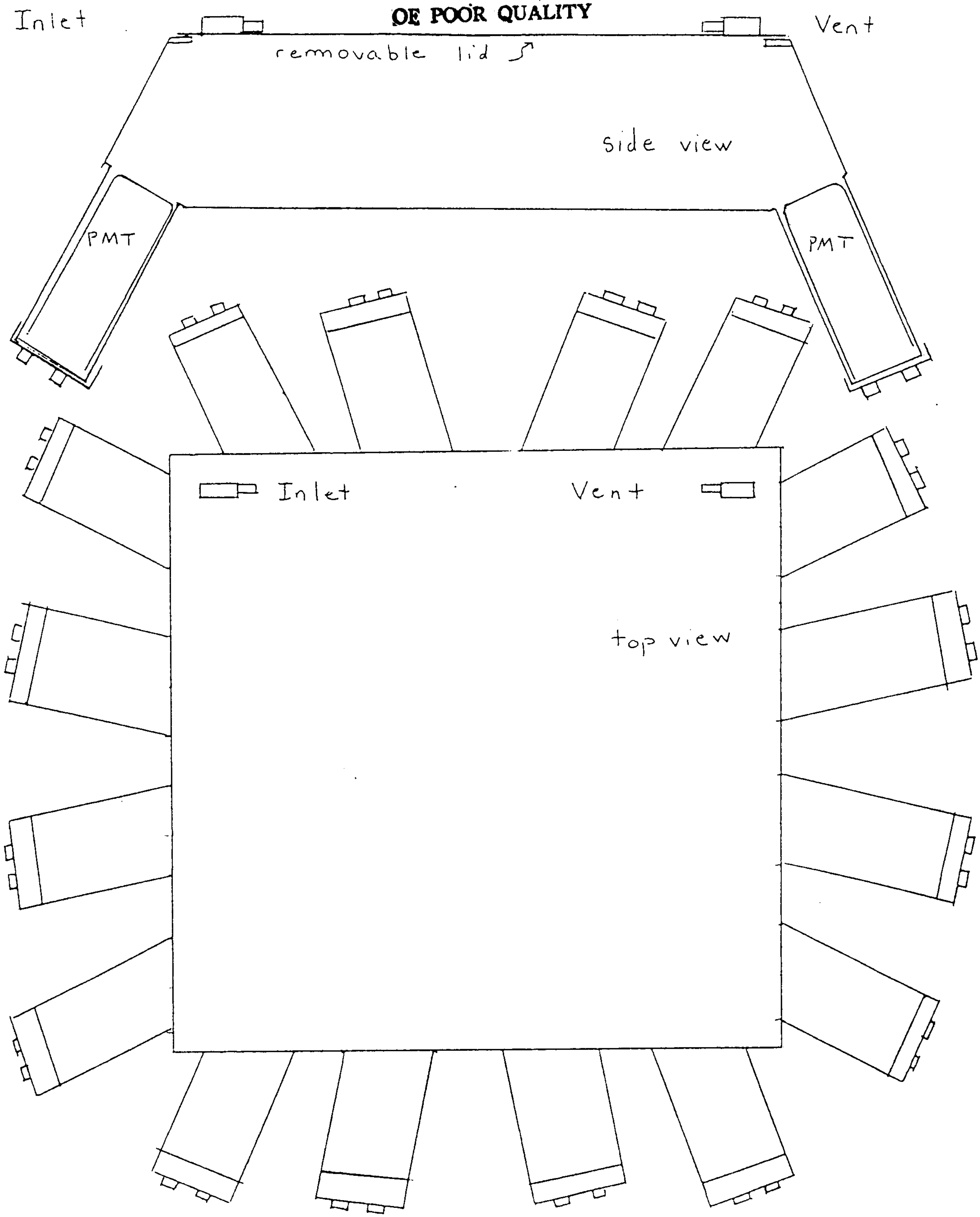

Fig. 2. Aluminum box which surrounds the Plexiglas box and FC72, insuring light-tightness. The 16 Hamamatsu R2490-01 photomultiplier tubes (PMT's) view the FC72 along the four sides.

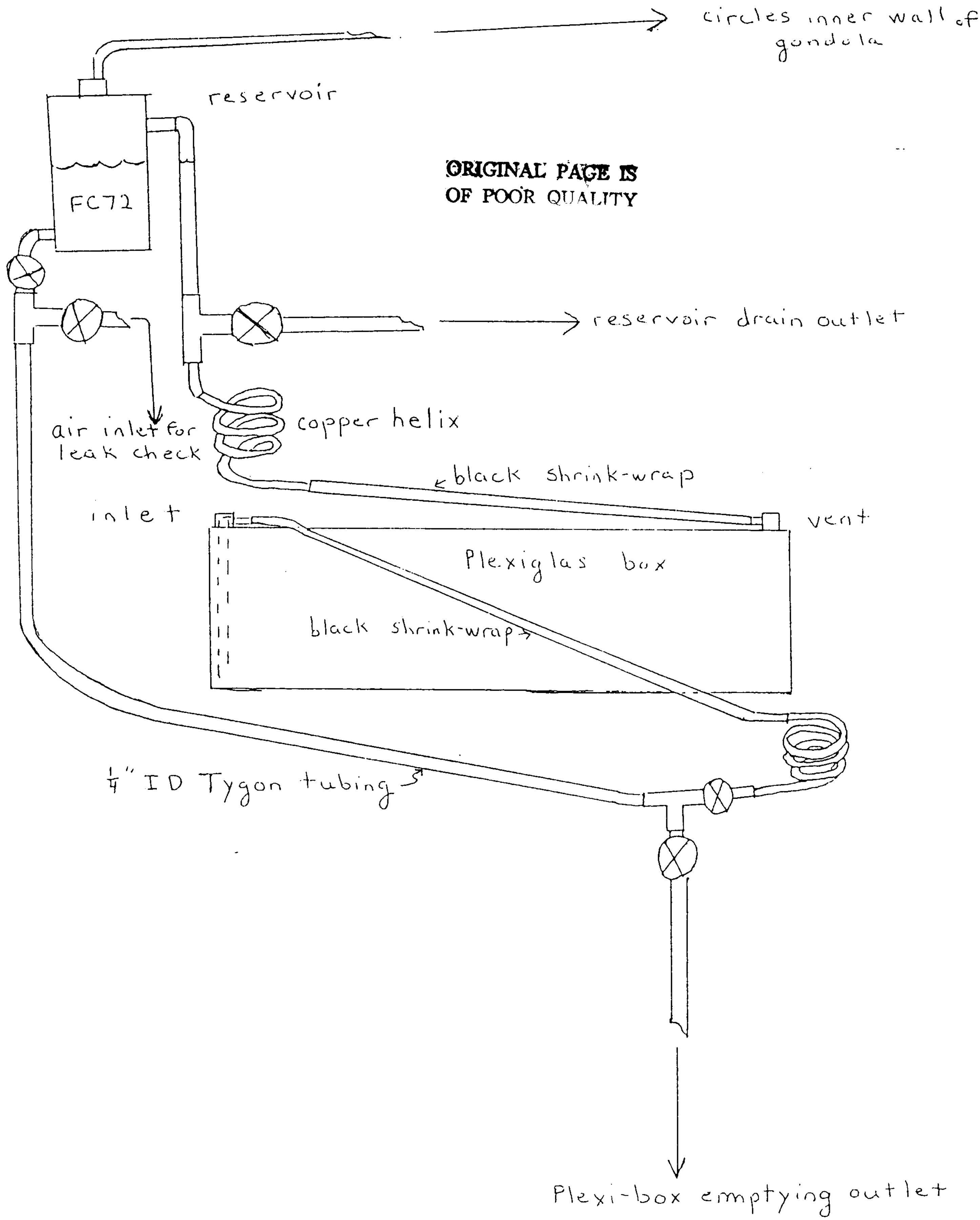

Fig. 3. FC72 filling system, with 2 liter capacity auto radiator overflow reservoir.

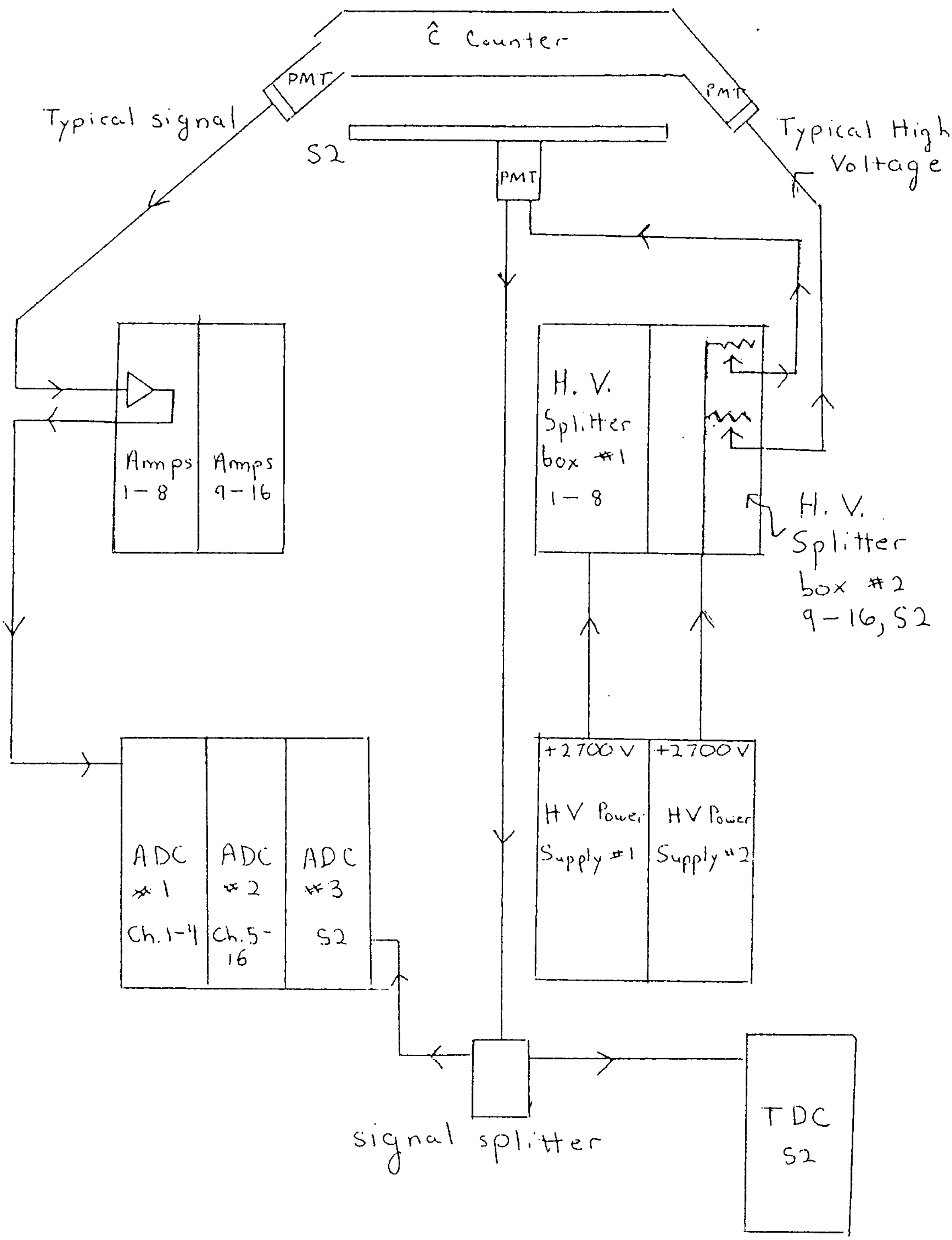

Fig. 4. Wiring block diagram of Cherenkov counter and S2 scintillation detector in LEAP.

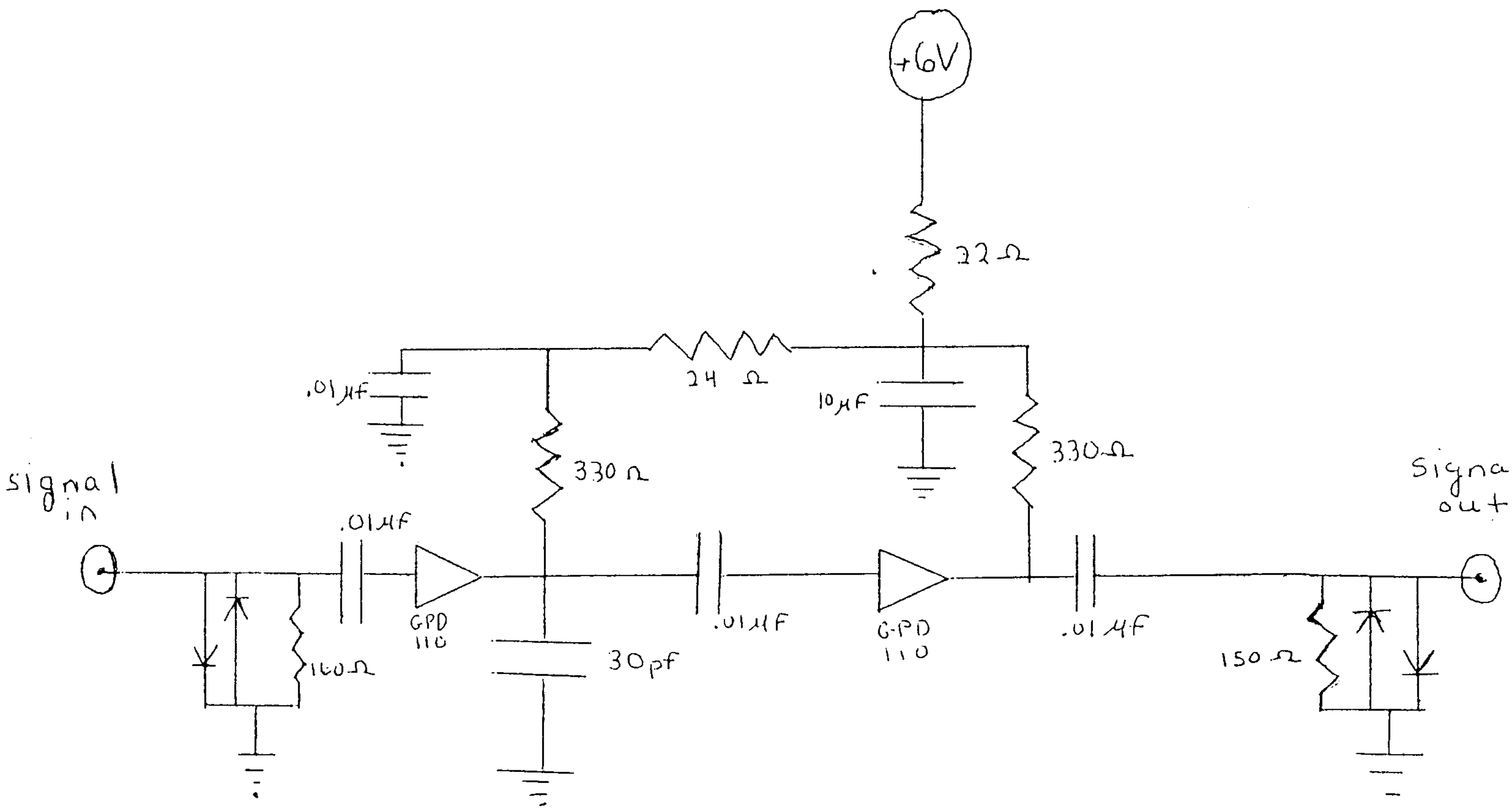

Fig. 5. Pulse amplifier circuit, utilizing Avantek GPD-110 high frequency amplifiers. Each NIM module contained eight identical amplifiers.

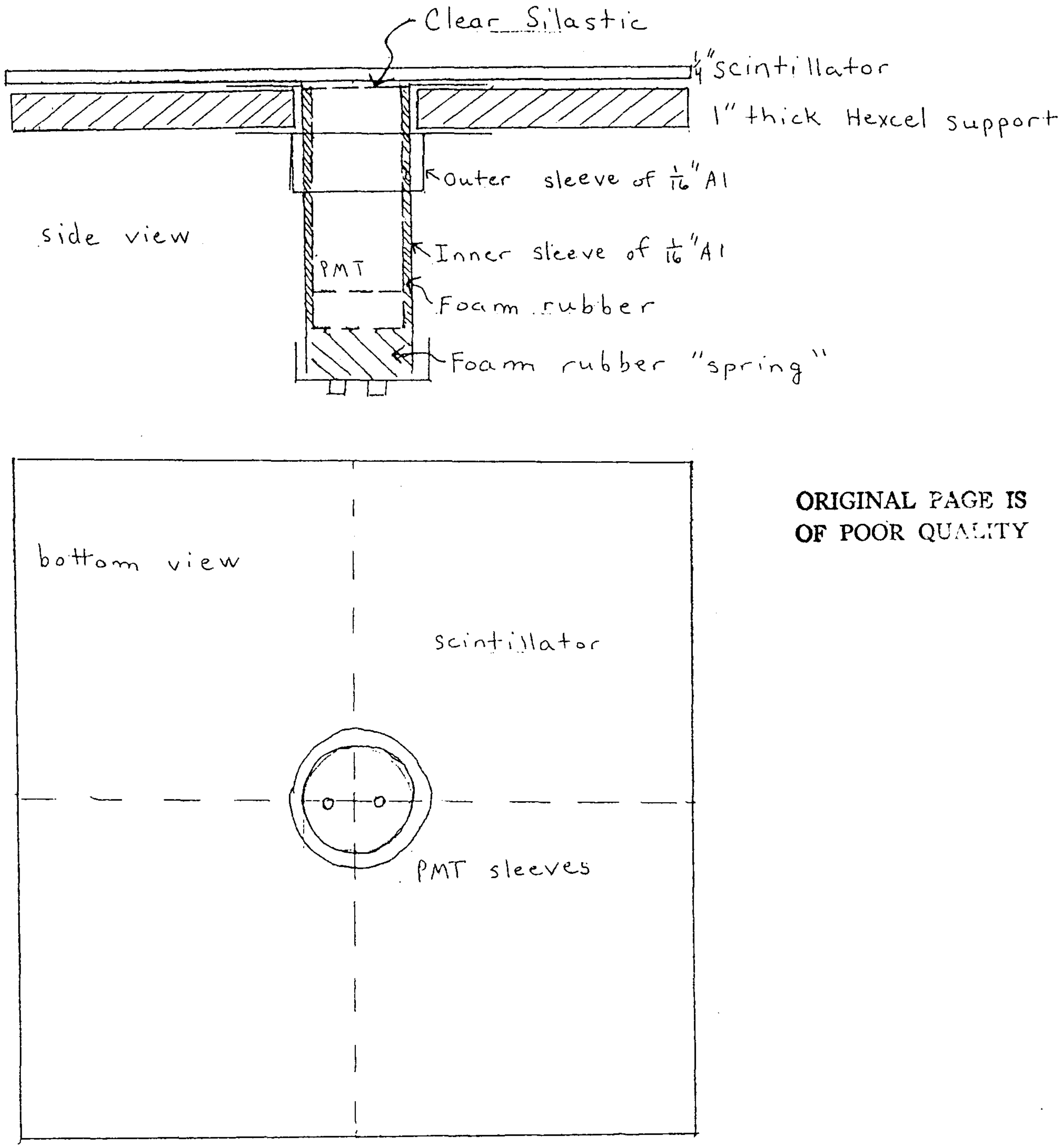

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Fig. 6. Scintillation detector S2. The plastic scintillator itself measures 17.5" x 17.5" x .25". A layer of aluminum foil covers the plastic; a layer of black optical tape covers the aluminum foil. A Hamamatsu R2490-01 PMT is held in place by two aluminum sleeves and views the plastic through a thin layer of silastic and optical coupling gel.

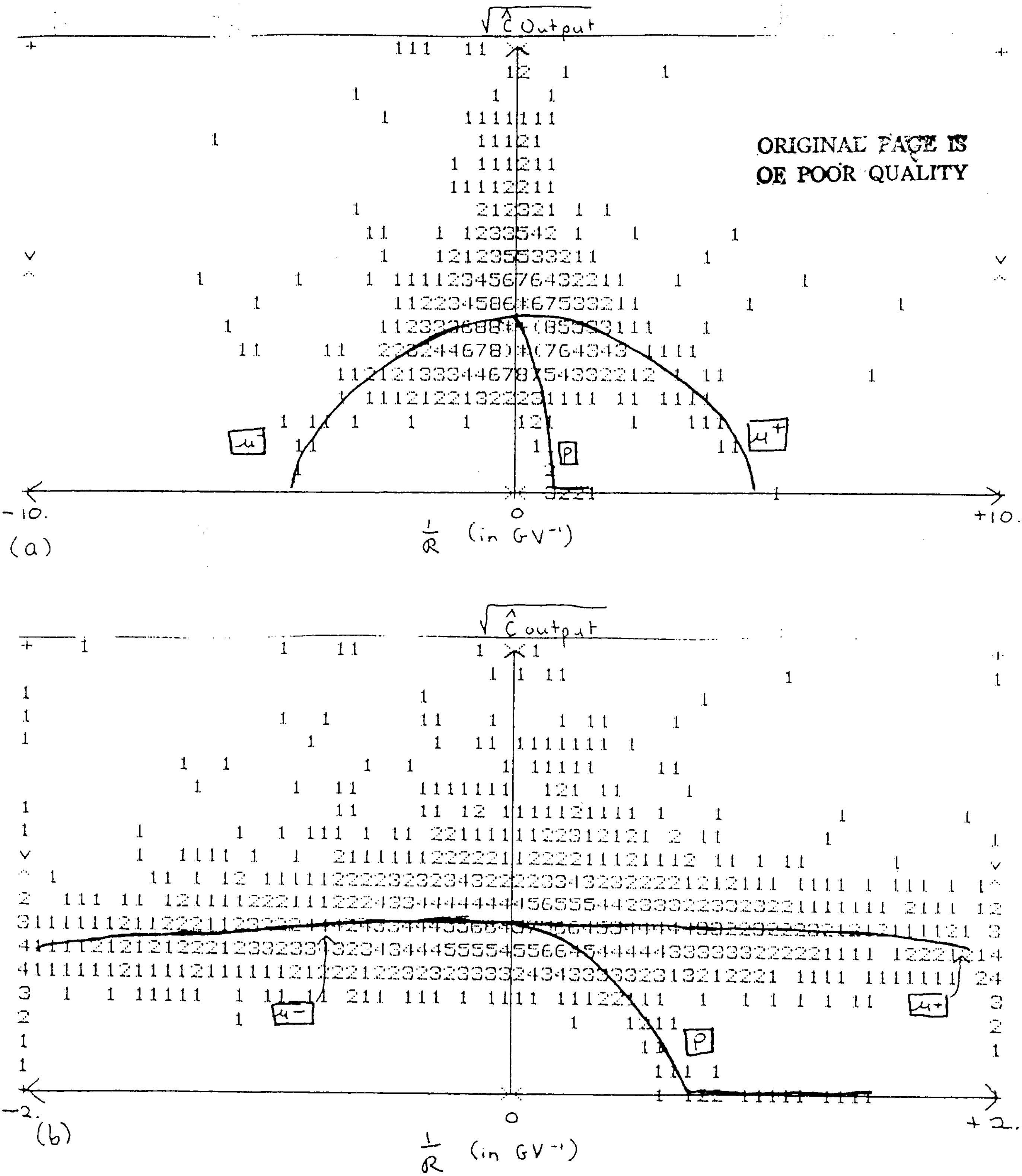
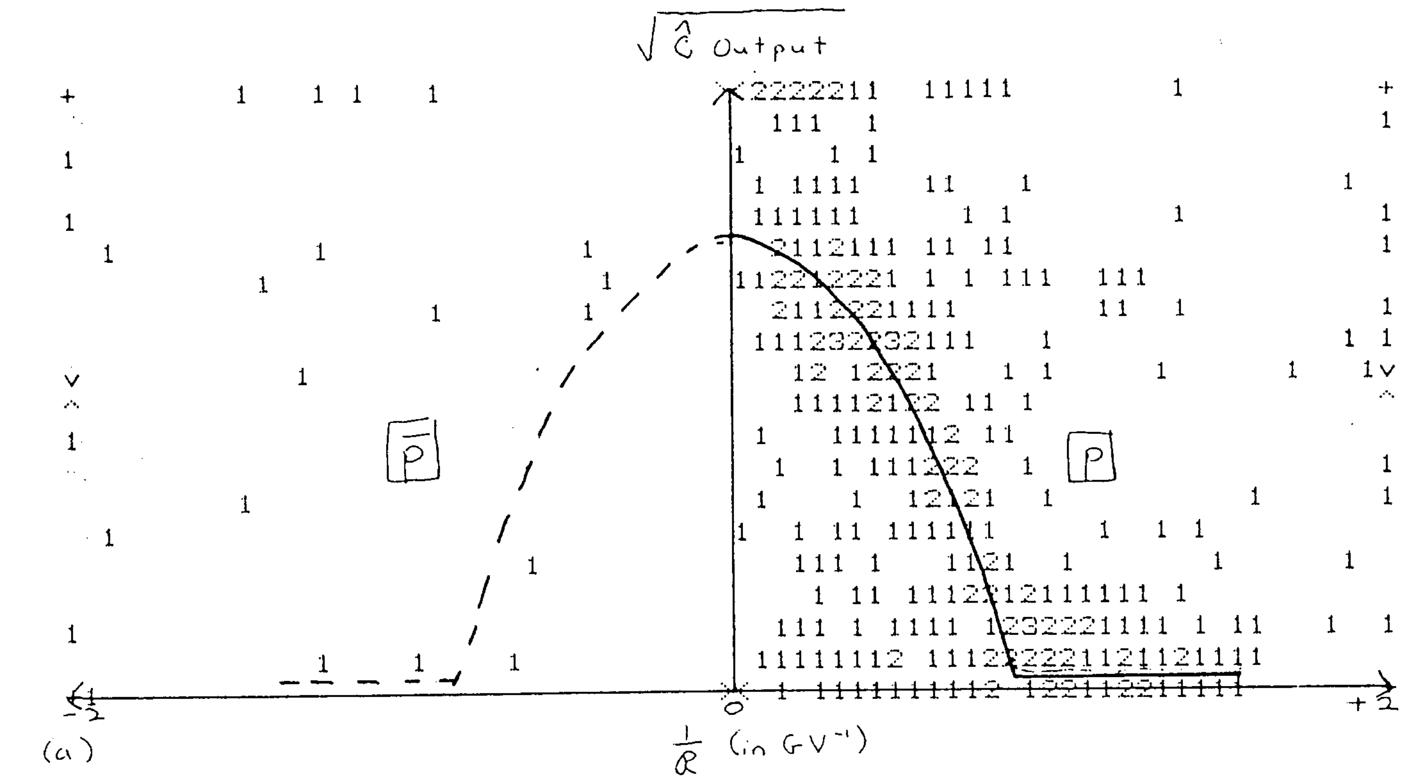


Fig. 7. (a) Square root of the total Cherenkov output from all 16 PMT's versus the inverse rigidity of the particles. Each species will form an ellipse, which can be seen above. Each number represents the square root of the number of events.
(b) The same with a different scale on the x-axis, allowing the proton band to be seen more clearly. All of this data was obtained on the ground at Prince Albert, Canada.



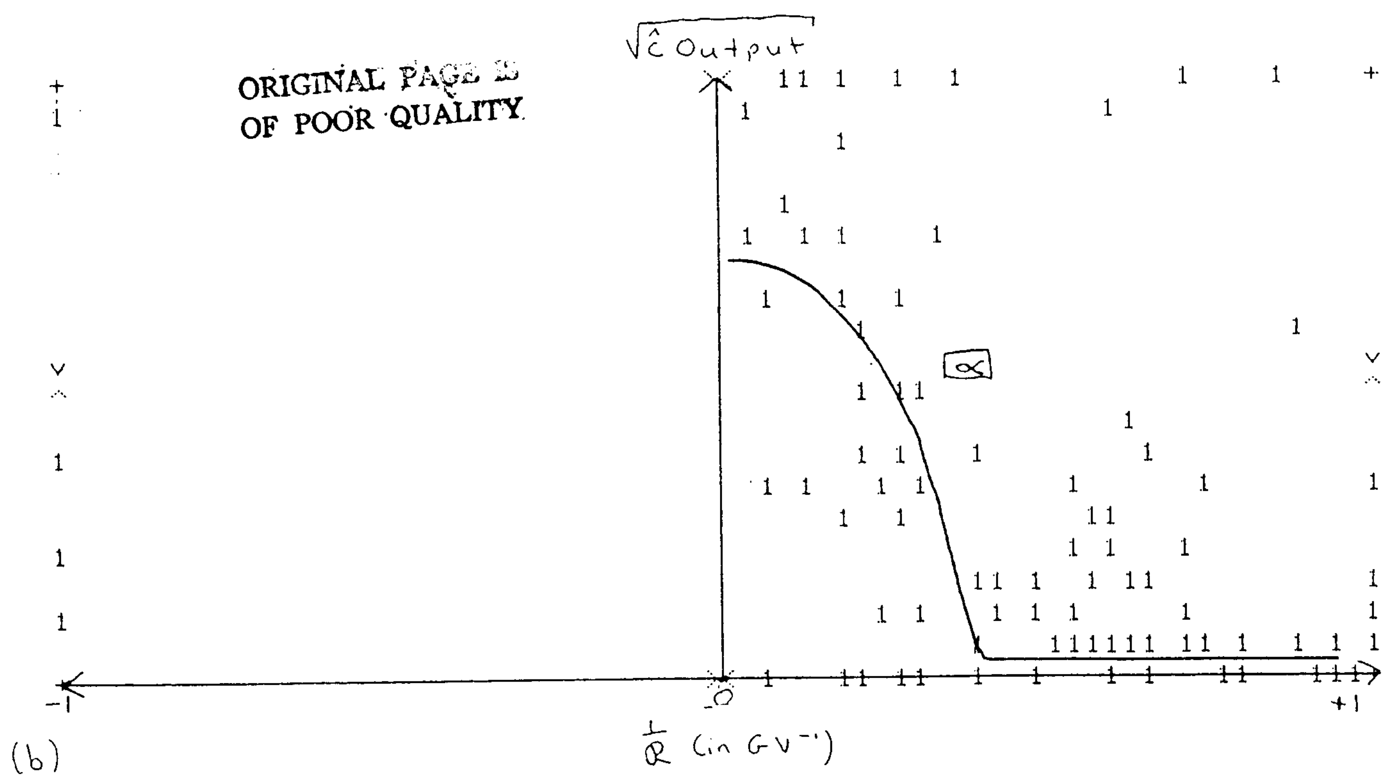


Fig. 8. (a) Square root of the total Cherenkov output from all 16 PMT's versus the inverse rigidity while LEAP was at float altitude. (b) The same as in (a), but with a different scale on both x- and y- axes so that the alpha particle band can be more clearly seen. Each number on the scatter plots represents the square root of the number of events.